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Transportation Research Procedia 2 (2014) 745 – 751

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The Conference on Pedestrian and Evacuation Dynamics 2014 (PED2014)

## Exploring the relationship of exit flow and jam density in panic scenarios using animal dynamics

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### Abstract

There are few studies investigating crowd dynamics in panic situations. They used measures such as exit flow rate to explore the exit performance in evacuation scenarios. However, there is limited research exploring the relationship of exit flow rate and density behind the exit for panic scenarios. This study presents a macro level analysis to investigate the relationship of exit flow and exit jam characteristics. Animal group behavior (i.e. panicked woodlice experiments) is utilized for data analysis. The results reveal that change in woodlice escaping behavior cause an increasing trend in exit capacity as the jam behind the exit increases.

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Peer-review under responsibility of Department of Transport & Planning Faculty of Civil Engineering and Geosciences

Delft University of Technology

**Keywords:** crowd dynamics; animal dynamics; panic scenarios; exit jam characteristics; exit flow

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### 1. Introduction

There are many occasions in which a large number of people are gathered together in a small area (e.g. attending a social function). In such events there are serious safety concerns in case of emergency evacuations since a huge number of people should evacuate the place in a relatively small time period. This may cause serious injuries and fatalities due to the pressure inside the jam. Architectural design of such places should be improved to minimize the

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number of casualties in evacuation scenarios. One main aspect of the design is the exit design in terms of size and location of the exit.

Several studies conducted to investigate exit design characteristics to improve pedestrian evacuation in normal and emergency scenarios (Daamen et al. (2007); Daamen et al. (2009); Schadschneider et al. (2009); Daamen and Hoogendoorn (2012)). However limited studies conducted to explore pedestrians' evacuation dynamics in panic scenarios (Helbings et al. (2000); Diorado et al. (2012)). This is due to the lack of appropriate data base for panic scenarios since these are rare events and it is almost impossible to obtain ethics approval for conducting experimental studies. Animal experiments have been recently utilized as a proxy to human experiments to explore panic scenarios (Shiwakoti et al. (2010), Dias et al. (2013)). Shiwakoti et al. (2011) and (2013) studied the improvement of exit design in panic scenarios using panicked ants. In these studies, they have used exit flow rate and exit headway distribution as measures to compare different exit designs. However, exit jam density and its relationship to exit flow rate is the other key parameter that have not been explored before. This is investigated in this article.

## 2. Experiment setting

Panicked woodlice data has been used in this study. Fig. 1 shows the details of the chamber design used for the woodlice experiments.

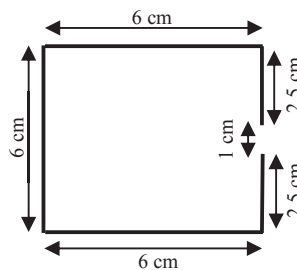


Fig. 1: Designed chamber for woodlice experiments

Fig. 2 presents the details of the experiment settings. As it is shown in Fig. 2, 120 woodlice are placed in the chamber. Initial position of the woodlice is behind the line that located 2.5 centimeters from the exit (see Fig. 2). This setting helps to prevent the woodlice to gather in front of the exit before the experiment starts.

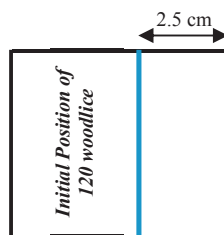


Fig. 2: Woodlice experiment settings

The woodlice escaping behavior is modelled using a special type of lamp which is used to simulate sun light for reptiles. This lamp can generate the lighting and heating in the level that is extremely dangerous for woodlice as they lose their body moisture very quickly. This forces the woodlice to escape from the light to survive. A safe place on the other side of the exit gate is designed to push the woodlice to run through the exit gate and reach the safe area. Consequently, a group of woodlice escape through the exit gate and this cause a big jam in front of the exit which can normally accommodate no more than 3-4 woodlice to pass. A snap shot of the experiment is shown in Fig. 3.



Fig. 3: Snap shot of woodlice experiment

### 3. Analysis results

Data analysis is carried on to estimate exit flow rate and jam density behind the exit. Tracker software is utilized to analyse the video recorded from the experiment. Two main steps are conducted for data analysis.

In the first step, exit flow rate is computed for each time step. In order to calculate exit flow rate the exit time of each woodlice is recorded. Exit Flow for each time step is computed as the number of woodlice evacuated the chamber at each time step divided by the time step duration.

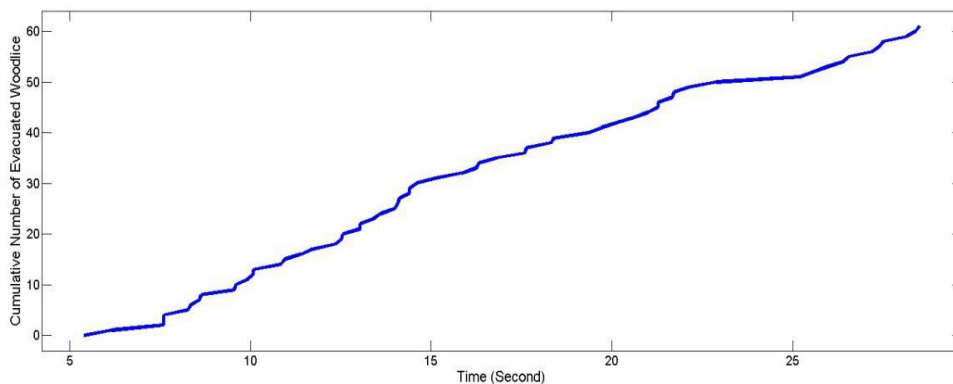


Fig. 4: Cumulative plot of number of evacuated woodlice

Fig. 4 reveals the cumulative plot of the number of evacuated woodlice. The slope of the plot shows the exit flow at particular time period. It is shown in the Fig. 4 that the exit flow is not constant at different times. In order to better understand how the exit flow changes over time, the plot of exit flow for each 0.48 seconds is drawn (see Fig. 5). This plot shows a clear fluctuation in the exit flow. This fluctuation could be due to temporary blockage that occurs in front of the exit and reduces the exit flow at the time of blockage. This trend is expected since conflicts take place among escaping woodlice running to the exit gate to evacuate the chamber. It is also expected to observe higher level of exit flow fluctuation as the level of stress in panicked agent increases. The next analysis step investigates how the exit flow rate variability is affected by the density in front of the exit.

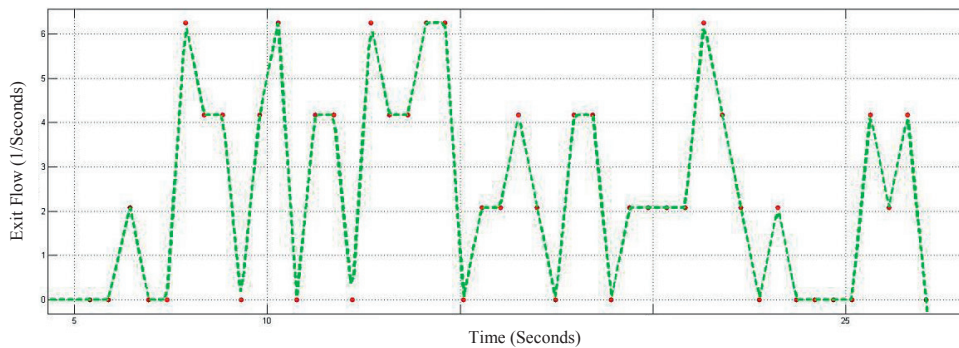


Fig. 5: Plot of exit flow for each 0.48 seconds

In the second step the jam area is identified and density behind the exit (exit density) is estimated for each time step. The jam area is defined as the area that covers the maximum jam taking place in the experiment. The video file recorded from the experiment is observed a number of times to identify the jam area. Then, the number of woodlice in the jam area is estimated at each time step. The exit density at each time step is computed as the number of woodlice in the jam area divided by the area of the jam. The relationship of exit flow and exit density is studied in this step.

The variability of exit density as a function of time is investigated first. Fig. 6 presents the plot showing the change in exit density based on time. The plot reveals an increasing trend in exit density in the first 10 seconds then the exit density starts to decline as the jam at the exit starts to disappear. This trend is quite logical. Similar trend can be observed in any bottleneck where the agents are queued up to pass through the bottleneck.

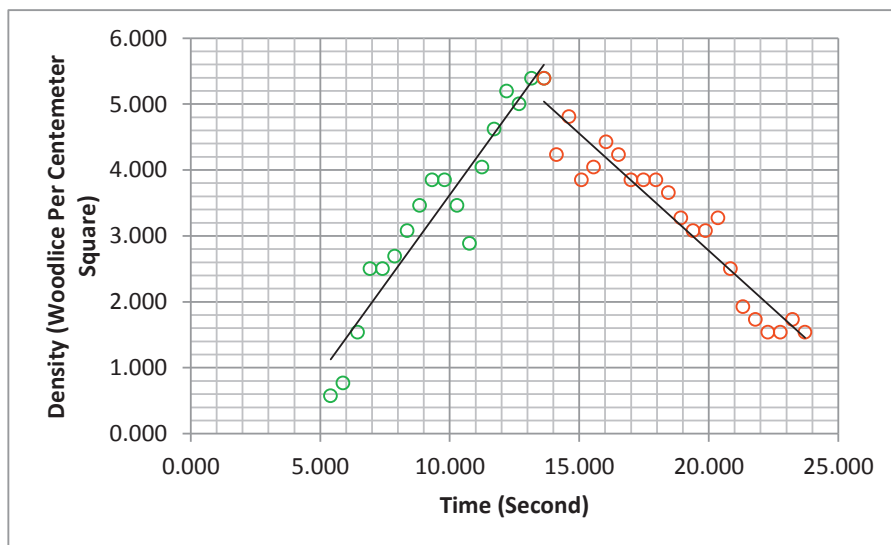


Fig. 6: Exit density-Time plot

Fig. 7 and Fig. 8 show the relationship of exit flow and exit density. Fig. 7 shows this relationship for increasing exit density (first 10 seconds) and Fig. 8 reveals this plot for decreasing exit density (see Fig. 6). As it is shown in these figures, the plot is drawn for two time steps which are 0.48 and 1.44 seconds.

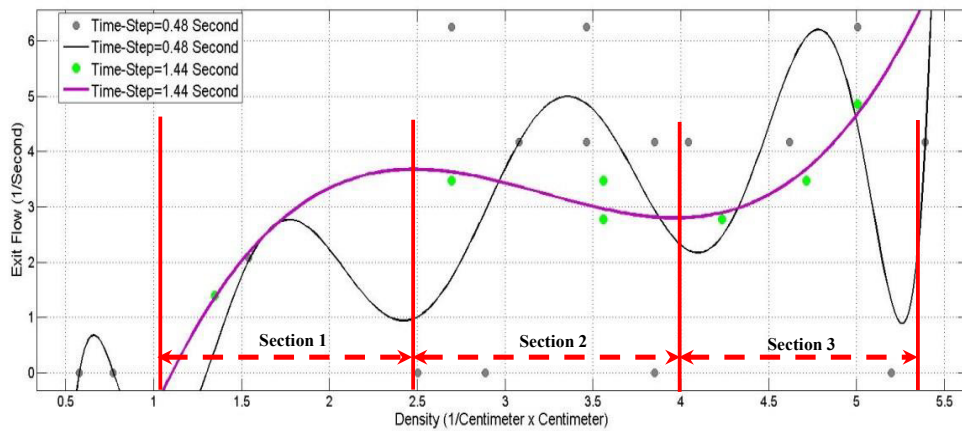


Fig. 7: Exit Flow- Exit density (increasing) plot (time-step: 0.48 and 1.44 seconds)

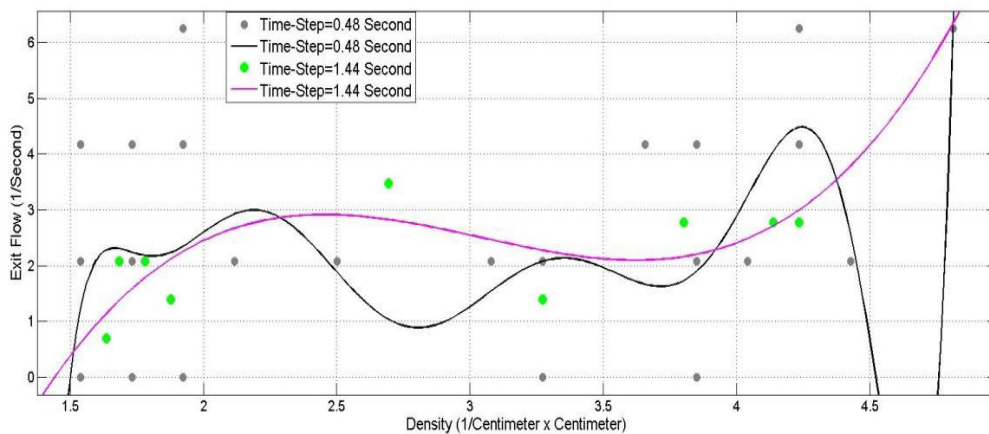


Fig. 8: Exit Flow- Exit density (decreasing) plot (time-step: 0.48 and 1.44 seconds)

According to the plot with shorter time step (0.48 seconds), two points can be highlighted:

- A fluctuating trend is observed for exit flow. This trend is expected as it is shown in the Fig. 5. As mentioned before, this fluctuation can be due to some micro level woodlice behavior such as conflicting maneuvers which can cause temporary blockage at the exit. As it can be seen in the Fig. 8 similar exit flow trend with generally lower values take place for decreasing exit density pattern.
- The exit capacity varies as the exit density increases. The Fig. 7 illustrates that in general there are four peak points for exit flow and there is an increasing trend for the peak points. This trend shows, in general, the exit flow is increasing for increasing exit density section (see Fig. 6). Fig. 8, on the other hand, shows a decreasing and then an increasing trend for the peak points as exit density decreases but in general, the exit flow is decreasing.

The results are more understandable as we consider the plot with longer time step (1.44 seconds). This plot creates a smoother diagram which helps to better understand the general exit flow trend for increasing and decreasing exit density sections (see Fig. 6).

For increasing density section (see Fig. 7), it is realized that first, there is an increasing trend in exit flow until the flow reaches the normal exit capacity which is 3.5 woodlice (in average). This peak point takes place for exit density of 2.5 woodlice per centimeter square. Then the exit flow starts to decline as the exit density increases. This trend continues until the exit density reaches 4.0 woodlice per centimeter square. Then, the exit flow takes an increasing trend as the exit density increases. Therefore, this plot can be divided into three sections. The first section presents the increasing exit flow trend as the exit density increased. The second section reveals a decreasing trend for increasing exit density pattern. Finally, in the third section the exit flow rate increases as the exit density increases.

This is a surprising result as it is expected to observe a fluctuating pattern in exit flow but it is strange to see as the exit density increases the exit capacity exceeds the normal capacity. After revisiting the experiment video, it is found that woodlice escaping behavior is the main reason for obtaining this result. As it is evident from the observed video, woodlice show two levels of escaping behavior. The change in behavioral level is directly proportional to the exit density which strongly affects level of pressure in the jam.

The first escaping behavioral level is defined as the normal escaping behavior. This behavior takes place in lower exit density when the number of woodlice in the jam area is low enough (less than 2.5 woodlice per centimeter square). This density allows the woodlice to pass through the exit with lower number of conflicts and use the normal capacity of the exit without any struggling behavior. This level of behavior is associated with the first section of the plot (see Fig. 7). If exit density exceeds a threshold (2.5 woodlice per centimeter square) the exit flow will be lower than the normal capacity (second section in Fig. 7). The exit density continues to increase and this causes a high pressure on the woodlice trapped in the jam. Thus, they start to show the second level of escaping behavior. In this level, they start to increase the exit capacity by passing over each other, changing their body direction to occupy less area and pushing each other strongly. These behaviors can double the exit capacity. This behavioral level is associated with the third section of the plot (see Fig. 7).

The same trend with lower values can be seen in for decreasing exit density (see Fig. 8). As a result, capacity increase is the phenomenon that can be observed in panic scenarios. Thus, it can be hypothesized to have a similar trend (with different threshold values) in panicked pedestrian evacuation.

#### 4. Conclusion

This paper explores the relationship between exit flow and density behind the exit (exit density) in panic scenarios. Panicked woodlice data has been utilized as proxy to pedestrian data since there is no available human data in panic situation. Woodlice experiment has been run for a square chamber with an exit located at the middle of the wall. The panic escape of the woodlice has been modelled using an especial lamp simulating sun light.

Two types of analysis have been carried on using the woodlice experiment. In the first analysis the variability of exit flow rate over time has been investigated. The results showed a fluctuating trend for exit flow rate. The main reason could be the behavior of woodlice in front of exit gate such as making conflicts which causes temporary blockage at the exit.

The second analysis is conducted to understand the relationship of exit flow and density in front of the exit (in jam area). The results confirm the fluctuating trend for exit flow as it was found in the first analysis. Furthermore it is found that there is an increasing trend in exit capacity as the exit density increases. This phenomenon is justified by observing woodlice behavior in front of the exit as the exit density is increased. Woodlice showed two different behaviors as they were passing through the exit. The first behavior appears when the exit density is low. In this case, woodlice behave normally since they do not need to struggle to get through the exit. The second behavior take place when the exit flow exceeds the exit capacity and the exit density continues to increase. In this case the jam pressure push the woodlice to change their coping behavior and start activities such as passing over each other, pushing each other strongly and changing their body direction to occupy less area. Therefore, they can double the exit capacity this way.

The results of this study reinforce this hypothesis that the capacity increase takes place in panic scenarios since the panicked agents are looking for a way to get through the exit and leave the jam pressure. Thus, it is hypothesized that similar exit flow trends can also be observed in panicked pedestrian evacuation.

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